Chapter 6[1]

Deep Space Station 15: Uranus—The First 34-Meter High-Efficiency Antenna

During the mid-1980s, The National Aeronautics and Space Administration (NASA's) Deep Space Network (DSN) introduced a new 34-m high-aperture-efficiency dual-shaped reflector antenna (see Chapter 1, Section 1.2.4, of this monograph) into the DSN (Fig. 6-1). The initial requirements were to provide a simultaneous receive-only capability at X-band (8.400–8.500 GHz) and S-band (2.2–2.3 GHz), to be used operationally for the first time in support of the January 1986 Voyager 2 spacecraft flyby encounter with Uranus, more than 3 billion km away. The 34-m antenna was used as one leg of a receive array system that also included the DSN's 64-m and the 34-m standard antennas. The addition of the new 34-m antenna added a nominal 0.8 dB to the 64-m and 34-m standard antenna array used for the Voyager Saturn encounter.

The 34-m high-efficiency (HEF) antenna is equipped with an electrically driven azimuth–elevation type of mount. The antenna dish is supported by a steel space frame that rotates in azimuth on four self-aligning wheel assemblies that ride on a precisely leveled circular steel track. The track is held firmly in place by 16 tangential links that attach to a centrally reinforced concrete pedestal. The antenna dish structure is attached to the elevation gear wheel, which drives the antenna up and down. The operating speeds are 0.4 deg/s in azimuth and elevation.

Two significant radio frequency (RF) developments were the dual-frequency feed, which provides for simultaneous multifrequency operation

[1] Based on "Evolution of the Deep Space Network 34-M Diameter Antennas," by William A. Imbriale, which appeared in *Proceedings of the IEEE Aerospace Conference*, Snowmass, Colorado, March 21–28, 1998. (© 1998 IEEE)

Fig. 6-1. The DSS-15 HEF antenna.

without the use of the dichroic plate, and the dual-reflector shaping of the surface, which provides improved aperture efficiency.

6.1 The Common-Aperture Feed

In mid-1976, a program was initiated to develop an S- and X-band feed horn, with the objective to utilize a centerline (CL) symmetric unit to replace the then asymmetric, simultaneous S-/X-band reflex DSN feed systems, thereby eliminating the dichroic plate (see Chapter 1) and further optimizing X-band performance, with degradation of S-band performance allowed if necessary. This feed was also to be capable of high-power transmissions in both X- (7.145–7.235 GHz) and S- (2.110–2.120 GHz) bands.

The basic concept for the horn design came from a paper by Jueken and Vokurka [1]. In essence, that paper recalls that the corrugation depths for a corrugated horn need to be between $\lambda/4$ (λ = wavelength) and $\lambda/2$ to support the proper (hybrid) HE_{11} waveguide mode. It follows that any such corrugations would be odd multiples of these depths within certain other frequency bands as well. A careful choice of depth is then made to obtain operation within S-band and X-band, with depths greater than $\lambda/4$ and less than $\lambda/2$ in S-band and greater than 5 $\lambda/4$ and less than 3 $\lambda/2$ in X-band. Thus, a sort of "harmonic" operation of the corrugation depth is effected. As such, a feed horn with fixed flare angle is made longer; hence, with larger aperture, a point is reached when further increase in length does not increase horn gain or reduce an associated beamwidth. Details of pattern shape will differ with frequency, but not with gain or beamwidth. One might call this saturated gain operation. Further details of this approach may be found in [2–4].

Injecting or extracting S-band is accomplished by feeding the horn at a sufficiently large horn-diameter region (above waveguide cutoff) from a surrounding radial line. The signal is injected into this radial line from four orthogonally located peripheral feed points excited in a 90-deg phase progression to develop circular polarization (CP).

The radial line carries two radial chokes, which prevent X-band from propagating within the S-band injection device, now termed the X-/S-band combiner. The system works very well at X-band, since no noise-temperature increase was noted when this feed horn was compared to the DSN standard X-band 22-dB horn, which has no S-band operation. Several combiner designs were explored, including a first-generation combiner with only a narrow S-band bandwidth suitable in a receive-only system, a second-generation combiner that would enable low-power (20-kW) transmission at S-band, and a third-generation combiner aimed at high-power (400 kW) S-band. The third-generation combiner was sufficiently immature at the time of the HEF antenna construction that the second-generation combiner was used [5].

Figure 6-2 shows the feed horn that was installed and tested in the Deep Space Station 13 (DSS-13) 26-m parabolic reflector. This R&D feed was installed in a four-function feed cone (Fig. 6-3) and was the first simultaneous dual-band receive/dual-band transmit DSN system [6,7]. A version of the feed cone was first tested at DSS-13 before a contract to manufacture the feed cones to be installed on the operational antennas was given to industry.

6.2 Dual-Reflector Shaping

Dual-reflector shaping consists of creating slight distortions of the usual hyperboloid subreflector of a Cassegrain system so that the feed-horn pattern can be transformed into a nearly uniform illumination across the main aperture. When this occurs, the uniform phase pattern, normally present from the hyperboloid, is destroyed. This uniform phase is then recovered by compensating for the distortions by modifying the main paraboloid. The resulting uniform distribution of amplitude and phase gives the maximum possible illumination efficiency available for the given aperture size.

Since the shaping transforms a feed-horn pattern, it follows that a particular feed-horn pattern must be used to obtain the final reflector shape. Geometric optics (GO) is used to solve the problem, and uses only equal path lengths, Snell's law of reflection, and conservation of energy, so frequency of operation does not enter into the solution. Therefore, any feed-horn pattern at any frequency and reasonably uniform phase will be transformed to an illumination

Fig. 6-2. Photograph of the R&D common-aperture feed horn.

that will be distorted to an extent dependent upon the similarity of its pattern to the pattern that was used in the basic shaping design. This property is especially important for the dual-frequency feed, since the frequencies of operation are so widely separated. It is only necessary that the feed-horn patterns at the two frequencies be nearly the same. It must be mentioned that the standard paraboloid-hyperboloid Cassegrain system is only a special case of the general shaped dual-reflector antenna. In that case, the transformation is 1 to 1, that is, the feed-horn pattern is unchanged. The illumination becomes that of the feed horn used in a prime-focus system of greater focal length, modified slightly by finite reflector diffraction detail.

Several modifications of a standard dual-reflector shaping algorithm were incorporated into the design. First, illumination in the central region was eliminated, reducing subreflector blockage and improving blockage efficiency by synthesizing what previously had been termed a vertex matching plate, but without the accompanying phase distortion. Second, the distance from aperture plane to main reflector (quasiparaboloid) vertex was chosen as a design parameter; this was done to match the geometries of the 26-m antennas of the DSN. Consequently, the special shape solutions closely approximate the 26-m paraboloid contour. The result was a feed-horn focal point location at 193.5 in. (4.915 m) from the quasiparaboloid vertex. Hence, the new feed horn is compatible with any other DSN antenna for maximum flexibility. Third, the geometric ray from the subreflector edge does not go to the main reflector edge but

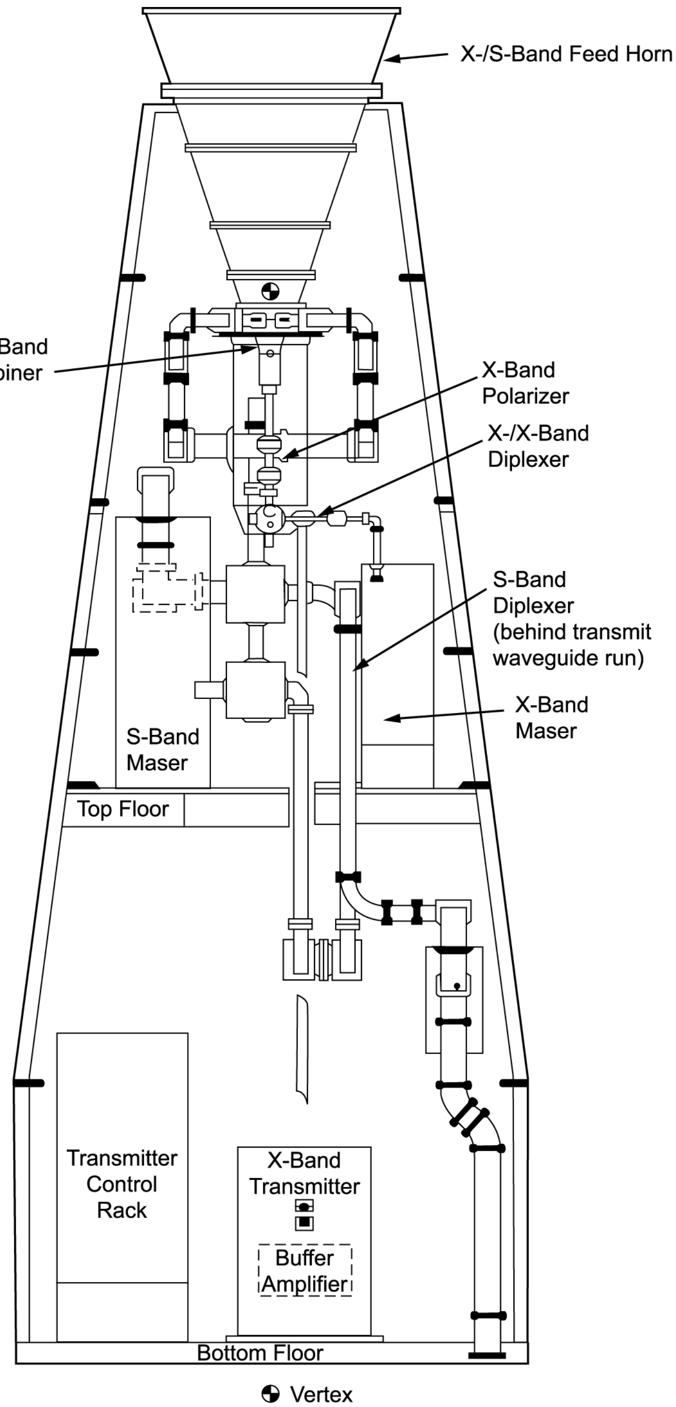

Fig. 6-3. Diagram of DSS-15 HEF antenna cone.

instead intercepts at 645 in. (16.383 m), as shown on the design control drawing (Fig. 6-4). The reason for this choice is as follows: The feed horn scattered energy from the quasihyperboloid does not fall abruptly to zero at the angle θ_1, but instead tapers rapidly to a low level. The angle θ_1, and, hence, the 16.393-m dimension, is chosen so that the intensity at θ_2 may be at a very low level relative to the central region of the main reflector, and the resulting rear spillover noise contribution becomes acceptably small. This procedure results in a slightly lower illumination efficiency, but the significant reduction in noise from rear spillover results in an optimum gain over temperature (*G/T*) ratio.

Figure 6-5 gives a plot of *G/T* versus edge illumination angle and justifies the choice of 645 in. (16.393 m) for the optical shaping limit. The measured pattern of the common-aperture feed horn at 8.45 GHz was used to calculate the surface shapes. The angular pattern through 17 deg was used so that the forward spillover (past the subreflector) was limited to <2 percent at X-band. The S-band pattern shape was similar, but nearly 9 percent of the energy was outside the 17-deg range. The improvement in gain from amplitude and phase distribution was nearly 1 dB.

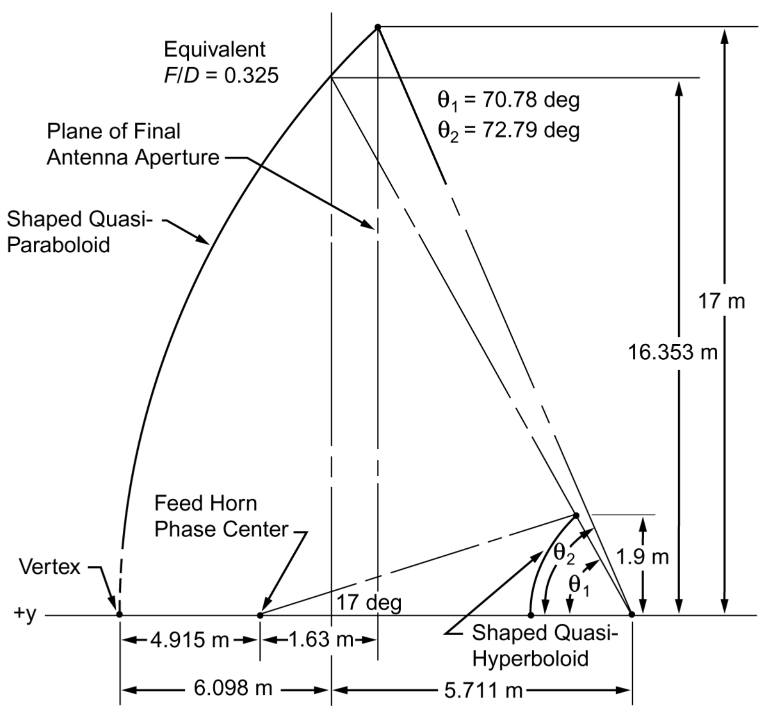

Fig. 6-4. Synthesis coordinate system.

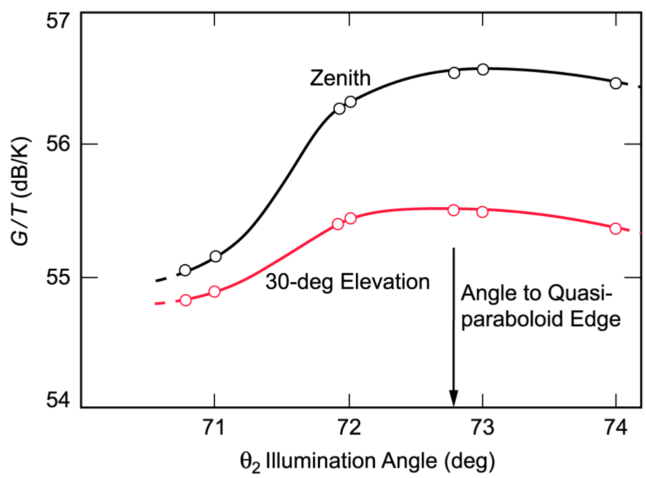

Fig. 6-5. *G/T* of system versus edge illumination angle.

6.3 Computed versus Measured Performance

The RF performance of the new HEF antennas was calculated by scattering the measured common-aperture X-/S-band horn patterns from the shaped reflector surfaces using standard physical optics (PO) computer codes. The RF efficiencies based upon the computer programs are given in Table 6-1 [8].

An estimate of noise contribution from the rear spillover is noted in Table 6-1. This is the average blackbody radiation from the ground, estimated to be 240 K multiplied by the percentage of energy in the rear spillover. Using holographic techniques, the root-mean-square (rms) surface error was measured to be approximately 0.5 mm. The efficiency numbers in Table 6-1 were derived using the Ruze formula. Area blockage due to the feed-support quadripod is estimated to be 6 percent, with the blockage efficiency determined from:

$$\text{Spar blockage efficiency} = [1 - 1.2(Ap)]^2$$

with Ap representing the percentage of geometric shadowing by the spars. Using the estimated rms surface area and quadripod blockage, the resulting expected efficiencies at the rigging angle are 75 percent (68.30 dB) at X-band and 67 percent (56.5 dB) at S-band. Measured X-band gain was 68.26 dB.

Table 6-1. DSS-15 efficiencies at S-band and X-band.

Element	S-Band	X-Band
Rear spillover efficiency	0.9746	0.9982
Resulting noise temperature contribution	(6.1 K)	(0.4 K)
Forward spillover efficiency	0.9110	0.9839
Illumination efficiency	0.9874	0.9823
Cross-polarization efficiency	0.9995	0.9988
Phase efficiency	0.9383[a]	0.9744
Central blockage efficiency	0.9765	0.9826
Dissipation, VSWR efficiency	0.9700	0.9700
RF efficiency	0.7779	0.8949
Spar blockage efficiency	0.8610	0.8610
Surface efficiency	0.9977	0.9692
Total efficiency	0.6682	0.7468
Resulting gain (dB)	56.4900	68.300

[a] The S-band phase center does not coincide with the 8.450-GHz phase center, resulting in somewhat poorer phase efficiency at S-band. (The feed-horn location and shaping are based upon the 8.450-GHz phase center.)

References

[1] E. J. Jeuken, and V. J. Vokurka, "Multi-Frequency Band Corrugated Conical Horn Antenna," *1973 European Microwave Conference Proceedings, Volume 2*, Brussels University, Brussels, Belgium, September 4–7, 1973.

[2] W. F. Williams, "A Prototype DSN X-S Band Feed: DSS 13 First Application Status," *Deep Space Network Progress Report 42-44*, vol. January and February 1978, http://tmo.jpl.nasa.gov/progress_report/issues.html Accessed April 9, 2001.

[3] W. F. Williams, "A Prototype DSN X- and S-Band Feed: DSS 13 Application Status (Second Report)," *Deep Space Network Progress Report 42-47*, vol. July and August 1978, http://tmo.jpl.nasa.gov/progress_report/issues.html Accessed April 9, 2001.

[4] W. F. Williams and S. B. Cohn, "Dual Band Combiner for Horn Antenna," U.S. patent No. 4199764, April 22, 1980.

[5] W. F. Williams and J. R. Withington, "A Common Aperture S- and X-Band Feed for the Deep Space Network," presented at the 1979

Antenna Applications Symposium, University of Illinois, Allerton Park, September 1979.

[6] W. F. Williams, and H. Reilly, "A Prototype DSN X/S Band Feed: DSS 13 Application Status (Fourth Report)," *Telecommunications and Data Acquisition Progress Report 42-60*, vol. September and October 1980, http://tmo.jpl.nasa.gov/progress_report/issues.html Accessed April 9, 2001.

[7] J. R. Withington and W. F. Williams, "A Common Aperture X- and S-Band Four Function Feedhorn," presented at the 1981 Antenna Applications Symposium, University of Illinois, Allerton Park, September 1980.

[8] W. F. Williams, "RF Design and Predicted Performance for a Future 34-Meter Shaped Dual Reflector System Using the Common Aperture X-S Feedhorn," *Telecommunications and Data Acquisition Progress Report 42-73*, January–March 1983, http://tmo.jpl.nasa.gov/progress_report/issues.html Accessed April 9, 2001.